CHAPTER 1: INTRODUCTION

Corals and coral reefs

Distribution of coral reefs

Coral reef ecology

Conservation of reefs

Marine National Park, Gulf of Kachchh

Lacuna

Aim and Objectives

1.1 CORAL REEFS:

CORAL REEFS are the most ancient and one of the fascinating ecosystems on the earth. They are the largest structures ever created by millions of tiny animals over thousands of years. Reefs being the prime productive zones of the oceans and morphologically cryptic, they are refuge to many thousands of flora and fauna in comparatively nutrient poor marine realm. Reefs are also referred as Oasis of the oceans harboring most diverse forms of life on the earth (Fig. 1.1). As per an estimate reefs support 0.5 million of species globally (Spalding *et al.*, 2001). The coral reefs are the best examples to experience all kind of inter-organism relationships at a place. In a coral reef environment many a species coexist, symbiosis and prey-predator relations are common phenomenon everywhere in reef environment (Dave and Mankodi, 2009a; Dave and Mankodi, 2010).

Geologically reefs/reef-like structures are dated to exist on earth for about 2,000 million years. The reefs of that time were of plant origin, dominated by calcareous algae, unlike modern corals. Then, during mid Ordovician period, first time tabulate and rugose reef corals appeared and replaced stromatolites, these reef community had built reefs around the tropical world and achieved optimum development in the Devonian Period. The Devonian reefs were abundant with rugose corals but mostly dominated by non coral organisms. But due to an unknown reason these diverse and abundant Devonian coral community suffered mass extinction at the end of the Paleozoic Era. The modern corals – Scleractinians evolved 245 million years ago in Mesozoic era. They were diverse and chief contributors in reef formations. The modern corals differ in skeletal properties from their counter parts of Devonian period by replacing Calcite with Aragonite. The Mesozoic reefs thrived well until many of the coral families disappeared by the end of the era. The survived families were further diversified into various reef building corals in the beginning of the tertiary period of the Cenozoic era. Thus, the modern known corals came in to existence in the world's reefs (Stanley, 2003; Veron, 2000).

"Reefs existed long before there were any Scleractinia on earth" – J. E. N. Veron

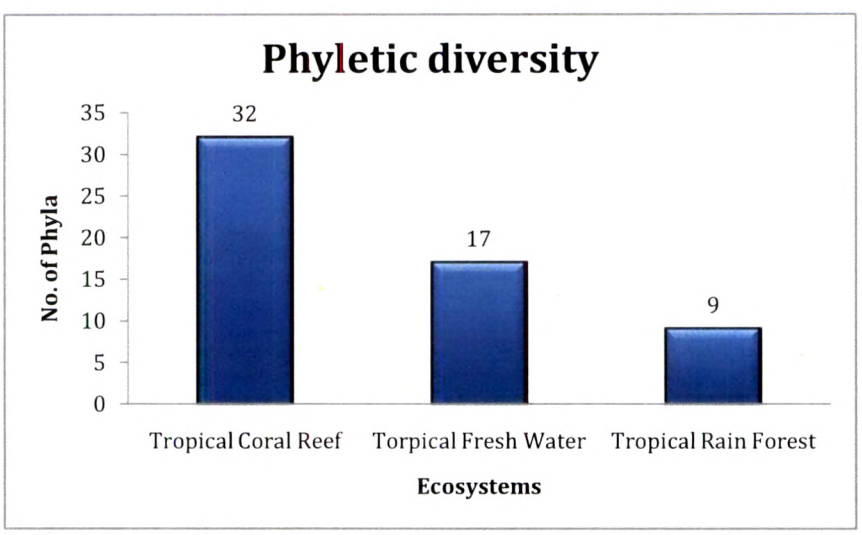
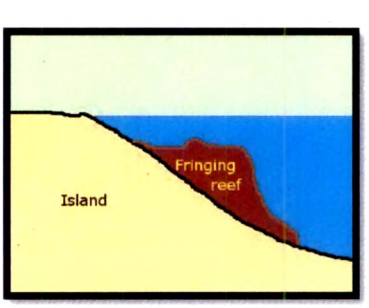


Fig. 1.1: Comparison of phyletic diversity across tropical ecosystems (Venkataraman *et al.*, 2003).

Coral reefs are mainly categorized into three types originally suggested by Darwin (1842) as follows:

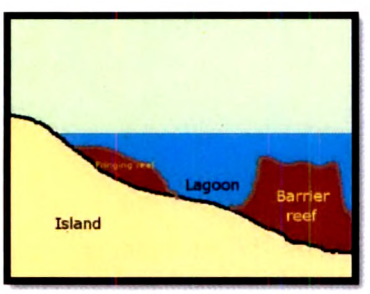
1. Fringing reefs:



Fringing reefs develop along the shore in shallow waters. A small lagoon may be present sometimes between the reef and coast. They are also known as shore reefs. They are the simplest reefs and are the early phase of reef formations. These reefs grow upwards to sea level and towards the open sea.

Fringing reefs can further be classified into reef zones like reef flat, boulder zone, reef edge/reef crest and seaward slope. The reefs of Andaman and Nicobar Islands and Gulf of Mannar are of fringing reef type (Venkataraman *et al.*, 2003).

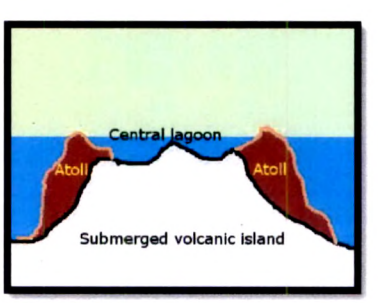
2. Barrier reefs:



Barrier reefs develop along the edges of continental shelves and/or around islands that have become partially submerged, and are separated from mainland or island by a wide, deep lagoon of about 20-100m depth. Corals grow more on the lagoon side of the barrier than on the open side where they have to withstand rigorous waves. The barrier reefs can also be classified into zones like the fringing reefs.

The "Great Barrier Reef" of Australia is the most famous example of barrier reefs. The reef is spread in Coral Sea along the northeastern coast of Australia for over 2000 km. Barrier reefs are also found in Andaman and Nicobar Islands (Venkataraman *et al.*, 2003).

3. Atoll reefs:



Atoll reefs are initially the fringing reefs around volcanic islands, subsequently the island subsides because of tectonic activities or sea level rising, the fringing reef forms a circular barrier reef separated from the island by a lagoon. Then the island finally disappears and the circle of reefs is left, sometimes capped with small coral islands, enclosing lagoons. The whole structure is called an Atoll.

The world's largest atoll "Suvaida" is located in Maldives. The reefs of Lakshadweep are the only example of atolls in Indian subcontinent (Venkataraman *et al.*, 2003).

Apart from the main 3 types, reefs are further classified in to platform reefs, patchy reefs, coral pinnacles, knolls etc.

1.2 CORALS:

Corals are tiny invertebrate life forms, exclusively marine and sedentary animals. They belong to Phylum Cnidaria. In ancient time the word "Coral" was used for precious red corals - *Corallium rubrum*. The term coral collectively applies to animals of Orders - Hydrocorallina, Antipatharia, Octacorallia and Scleractinia of this phylum which are commonly known as fire corals, black/deep-sea corals, soft corals and hard/stony corals respectively. The term more specifically refers to colonies of genetically identical individuals known as "Polyps" which secrete composite of calcium carbonate and other organic and inorganic elements to form exoskeleton (Sreekumaron and Gogate, 1972; Wainwright, 1964).

Corals are diploblastic and radially symmetrical animals like other cnidarians. Their body cavity (coelenteron) opens through an opening - the mouth, that is surrounded by tentacles. The gastric cavity of polyps is vertically divided by mesenteries/septa. The polyps bear batteries/nematocysts in the tentacles and other body parts which are defense organs and help in capturing tiny preys also (Fig. 1.2).

The hard coral can reproduce sexually and asexually. Generally they adopt asexual mode to grow colony size. Majority of hard coral colonies are hermaphrodite, however a few percent of total population may be unisexual possessing only male or female sex organs (Veron, 2000). The hard corals have been reported to reproduce sexually anytime of the year by releasing (spawning) gametes in the water which get fertilized outside and form planula larvae. Pandey *et al.* (2010) have stated the strong effect of photoperiodicity, water temperature, tides and lunar phase on the mass spawning that occur during specific times of year. The planula settles to hard substratum after initial free swimming life and develops in to juvenile polyps which lead to colony formation asexually.

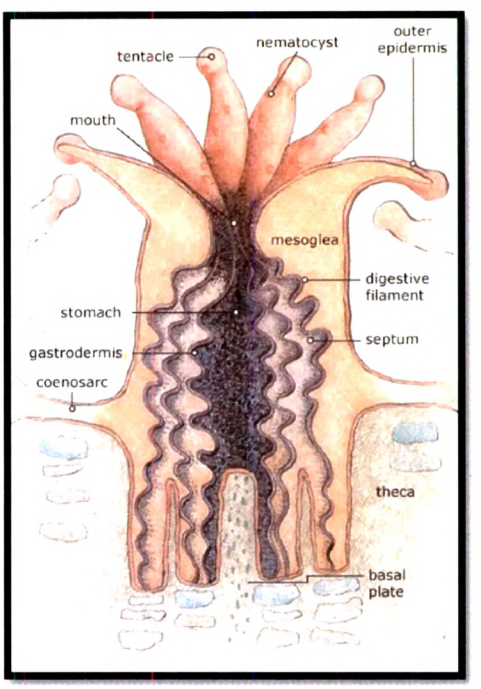


Fig. 1.2: Anatomy of a coral polyp (Source: NOAA).

The scleractinians are the unique examples of plant-animal symbiosis. In many hard corals photosynthetic dinoflagellates (genus *Symbiodinium*) commonly known as Zooxanthellae are present inside the polyp's endodermis, especially in tentacles and oral disc (Trench, 1987). These endosymbionts not only utilized the organic waste created by their host but also promotes calcification rate of the host by fulfilling its energy requirements (Stanley, 2003). Thus, the scleractinians with symbiotic algae are capable to produce massive structures of calcium carbonate and contributes in the reef formations. Based on this fact, the scleractinians are further classified into Hermatypic corals (with zooxenthelle) and Ahermatypic corals (without zooxenthelle), the former contribute into reef formations.

1.3 GLOBAL DISTRIBUTION:

Reefs are found throughout the world's ocean. Hard substratum, least turbid waters, water temperature between 20°C to 30°C and 36‰ salinity are the most essential requirements for coral to thrive at their optimum. Most of the scleractinian's distribution remained restricted to the tropical shallow waters between 30°N and 30°S latitudinal limits (Fig. 1.3) as they require sunny environment to facilitate their endosymbiont algae - zooxanthellae. However, azooxenthallate corals can thrive in darker regions and withstand colder temperatures. Distribution of antipatharian corals (black corals) has been reported up to abyssal depths of beyond 2,000m. The reefs cover about 284,300 square kilometers which is just one tenth of one percent of the oceans' surface area (Spalding *et al.*, 2001).

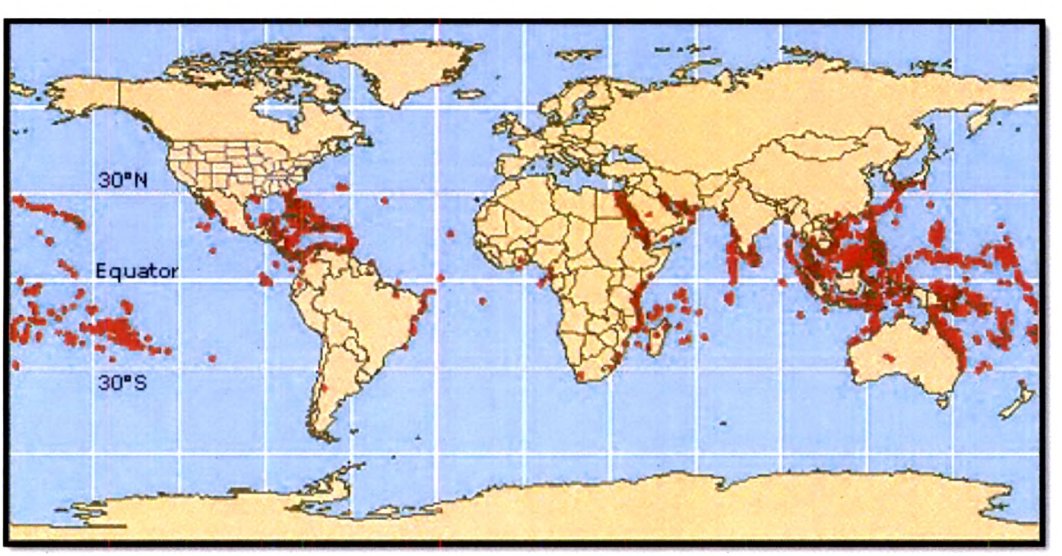


Fig. 1.3: Global distribution of coral reefs (Source: NOAA).

Table 1.1: Global area coverage of coral reefs.

Region	Area (km^2)	% of the world total
Indo-Pacific:	**261200**	**91.8**
Indian ocean	91700	32.2
Southeast Asia Pacific	115900	40.8
Red Sea and Gulf of Aden	17400	6.1
Arabian Gulf	4200	1.5
Arabian Sea	32000	11.3
Atlantic and Caribbean:	**21600**	**7.6**
Atlantic	1600	0.6
Caribbean	20000	7.0
Eastern Pacific	**1600**	**0.6**
Total	**284400**	**100.00**

(Spalding *et al.*, 2001)

1.4 INDIAN DISTRIBUTION:

Indian reef regions fall into Indo-Pacific reef zone. The Indian reefs can be divided roughly into four major reef regions (Fig. 1.4) viz. Andaman and Nicobar Islands, Gulf of Mannar and Palk Bay, Lakshadweep and Gulf of Kachchh (Venkataraman *et al.*, 2003).

The Andaman and Nicobar islands lies in southeastern direction in the Indian Ocean. The reef region represents the highest generic diversity of scleractinians from the Indian waters. The Andaman and Nicobar reefs are nearer to the Indonesian coasts therefore the coral diversity of this region is more similar to that of the Indonesian and the Southeast Asian reefs (Bahuguna *et al.*, 2010). The islands have two Marine National Parks viz. Mahatma Gandhi Marine National Park and Rani Jhansi Marine National Park. All together 177 species of hard corals have been reported from Andaman and Nicobar Islands (Venkataraman *et al.*, 2003).

Gulf of Mannar and Palk Bay, the third most important coral reef region of India, is located along the southern coast of Tamil Nadu state. These reefs had suffered large scale quarrying of coral blocks by construction industries before the declaration of the Gulf of Mannar Marine National Park in 1986 and subsequently in the year of 1989 the Gulf of Mannar was declared as "Marine Biosphere Reserve" (Bahuguna *et al.*, 2010;

Patterson *et al.*, 2008). Gulf of Mannar and Palk Bay reefs have been reported to have 82 species of corals, however recent surveys have reported all together 117 species of hard corals (Patterson *et al.*, 2008; Venkataraman *et al.*, 2003).

Lakshadweep Archipelago is situated in the Arabian Sea in the southwest direction about 200-470km off the Kerala coast (Bahuguna *et al.*, 2010). Lakshadweep reefs harbors 91 species of hard corals and forms the second most diverse Indian reef region (Venkataraman *et al.*, 2003).

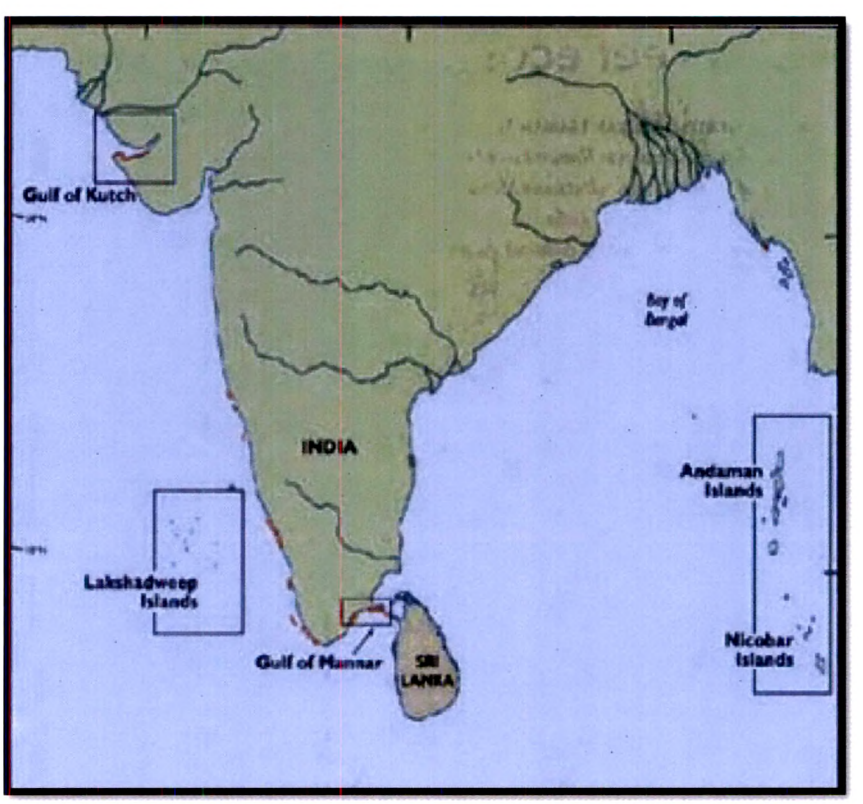


Fig. 1.4: Major Coral reef regions of Indian subcontinent (Source: www.reefindia.org).

Gulf of Kachchh (GoK), an indent of Arabian Sea into mainland of Gujarat, is the fourth major coral reef region of India. Fringing, platform and patchy types of reefs are found along the southern coast of the Gulf. No barrier and atoll reefs are found in the GoK. This reef region forms the northern reef formations of Indian Ocean. The GoK receives heavy load of sediments from the Indus river (Kunte *et al.*, 2003). Further, geographic isolation from other coral reef areas of India and extreme environmental conditions are the main factors for the least coral diversity of this reef region among the major Indian coral reef regions (Pillai and Patel, 1988). Early studies have reported 36 species of hard corals occurring in GoK, the list was then updated to 45 species recently (Dixit *et al.*, 2010; Pillai and Patel, 1988).

Further, apart from the above mentioned major reef regions, distribution of corals in form of patchy reefs and otherwise on rocky intertidal area has been reported along Vizhinjam, Mangalore, Gaveshani Bank, between Vengurla and Vijaydurg, Redi Port, Malwan, Bombay High (near Mumbai) on the west coast of India (Jasmine *et al.*, 2009; Nair and Qasim, 1978; Qasim and Wafar, 1979; Sen Gupta and Deshmukhe, 1999).

Coral reef area coverage of major Indian coral reef regions is summarized in table 1.2.

Table 1.2: Coral reef area of major Indian coral reef regions.

Sr. No.	Reef Region	Reef Area (km^2)	% of Indian reef regions
1	Andaman and Nicobar Islands	1021.463	42.85
2	Gulf of Mannar	75.93	3.19
3	Lakshadweep	933.70	39.17
4	Gulf of Kachchh	352.50	14.79
	Total	**2383.593**	**100**

(Bahuguna *et al.*, 2010)

1.5 CORAL REEF ECOLOGY:

The coral reefs are one of most dynamic ecosystems on the earth. A very fragile equilibrium amongst various biotic and abiotic factors is maintained in a very unique way. A slighter imbalance in the equilibrium may collapse the entire ecology and lead to the degradation of the coral reefs. Further, being the nearest to the ocean surface and shores the reefs undergo tremendous threats of anthropogenic and natural origin as well. Therefore, biodiversity, integrity of the fragile ecosystems, their functioning, response to climate change and threats etc. are a few subjects on which researchers have attempted to resolve the mysteries in the light of science. Following is a brief account of recent scientific studies on the coral reef ecology.

1.5.1 INTERNATIONAL REVIEW:

Coral reefs have been studied for their ecology, bleaching, diseases, degradation, reef associated fauna, intra-specific competitions, reef fishes and their economical values etc. worldwide. However, most coral reef surveys have been limited to discrete reefs or species or time limited (Bythell *et al.,* 1992; Dustin and Halas, 1987; Porter and Meier, 1992). Study of coral diversity of Arabian Gulf and the Gulf of Oman showed clear effect of geographical isolation and extreme environmental conditions with the decreased number of species and highly altered community structure, the Dendrophylliidae, Faviidae and Siderastreidae families were over represented than the most diverse family Acroporidae (Coles, 2003). Further, the coral and other sessile organisms' diversity was recorded to follow a consistent pattern of increase with depth up to 20m and then gradual decrease, this was attributed to the gradient of light energy (Huston, 1985). The same preference for illuminated places (substratum) was shown by coral larvae, the preference was found to be independent to depth contour for exposed microhabitats; the vertical microhabitats were second most preferred up to 17m depths whereas cryptic habitats were preferred below 20m depths (Edmunds *et al.,* 2004). However, on local scale the distribution of corals and other sessile organisms is mainly restricted by inter-specific competitions, predators and water movement/tides (Glynn, 1976; Tazioli *et al.,* 2007).

As Veron (2000) stated that the inability of *Acropora* to survive and dominate in slightly turbid waters, such habitats if protected from strong wave actions can turn out to be more diverse than their counterparts in the clearer waters in the depth.

Association or symbiosis is a common and very important phenomenon in reefs. Association between fish and anemones, shrimp and anemones, corals and bivalves are known examples. Associations such as seen between anemone fish and sea anemone helps to transfer nutrient from the outside of reef and contribute into overall productivity of reefs (Roopin *et al.*, 2008). Cost benefit study of the association between anemone shrimp *Periclimenes brevicarpalis* and their host sea anemone concluded the association is of benefit to the shrimp (Fautin *et al.*, 1995).

In contrast to the association between organisms, reefs are place to witness aggressive competitions for resources like food and space. *Palythoa* can dominate the marine sessile invertebrate community in various reef zones with about 2.5 mm/day growth rate, irrespective of physico-chemical environmental condition (Suchanek and Green, 1981).

Studies on corallimorpharians, revealed their aggressive behavior exhibiting the role of defensive mechanism of their tentacles and mesenteries in space competition with scleractinians and actiniarians (Chadwick, 1987; Miles, 1991). In *Rhodactis rhodostoma*, it was observed to over grow the branching corals with smaller corallites but could not challenge the massive corals with larger polyps, soft corals were found resistive to the corallimorph's stings (Langmead and Chadwick-Furman, 1999a). They were reported to occupy any left out space in reef with rapid growth though longitudinal fission, inverse budding, and marginal budding; their growth was found to be controlled by photoperiod and sea water temperature, by mean of cloning they can double them within a year (Chadwick-Furman and Spiegel, 2000).

The reefs are also threatened by various factors anthropogenic and natural as well. Sediment, sea temperature rise, outbreak of disease, anchoring, diving are a few to name. Physiology of corals under sedimentation loads showed lowered photosynthesis during the day and respiratory increase during night (Abdel-Salam *et al.*, 1988). Excess

fishing in reef areas leads to degrading the reef's food chain. Interestingly, reduced fishing does not only allow the reef fish stock to remain at minimal essential level, but also help in increase in number of grazers in reef ecosystem which promote the coral recruits by controlling macro algae (Mumby *et al.*, 2007).

Increase in ammonia, water temperature and decrease in dissolved oxygen was found to increase expulsion of symbiotic algae in corals leading to serious bleaching (Baohua *et al.*, 2004). Temperature beyond 28°C killed scleractinian larvae significantly, with inverse relationship to motility. Presence of ammonium also significantly decreased motility (Bassim and Sammarco, 2003). However, reduction in coral cover due to anchoring on reef areas was the prime factor than recreational diving and chemical pollution due to antifouling paints (Saphier and Hoffmann, 2005).

Many coral diseases have been recognized and their spread, causative agents and effect of climate have been studied. In recent, years number of coral diseases and their frequency of occurrence has increased, but our knowledge of the diseases, their progression and underlying cause is very limited (Kim *et al.*, 2009; Sokolow, 2009). A detailed structural and microbiological investigation revealed the difference between looking alike disease – the white syndrome and white disease (Ainsworth *et al.*, 2007). Extensive disease outbreak was observed coinciding with upwelling and increase in nutrients and toxic algae (Coles, 1994). A new kind of disease from Southern Arabian Gulf was entitled "Yellow Band Disease", which was found to affect *Acropora, Porites,* and *Turbinaria* with rapid spread in summer than in winter (Korrubel and Riegl, 1998). Further, field experiments suggest that 2 to 5 time increase in nutrients in reef environment is sufficient to double the tissue loss by the yellow band disease (Bruno *et al.*, 2003). However, increase in macro algae due to depletion in grazers has no relation with yellow band disease outbreak in Caribbean reefs (Vu *et al.*, 2009). This suggests that alteration in water chemistry due to excess nutrients promote outbreak of yellow band disease and not the increase in macro algae due to nutrient influx. An interesting conclusion was drawn from wide range of literature available on disease outbreaks and spread in marine ecosystems that over the period of about 30 years a clear increasing trend of disease prevalence was observed in turtles, corals, mammals,

urchins and molluscs (Ward and Lafferty, 2004). Another study on a hypothesis stating the co-occurrence and close association between octacoral and scleractinian diseases resulted into no association between them and non consistent relationship between disease and the diversity measures, but the dominant species of both the groups are susceptible to infection with several disease and that can result into diversity alteration (Ward *et al.*, 2006). In Great Barrier Reefs, significant positive correlation was seen between the occurrence of warm water anomalies and outbreak of white band disease, however, high coral cover (>50%) was found necessary for the disease outbreak (Bruno *et al.*, 2007; Selig *et al.*, 2006). It was opined that might be due to coinciding increase in bleaching events, the hosts (corals) became more susceptible to the virulence and caught into diseased stage, the hypothesis was found in the *Acropora palmata* colonies which showed more disease related mortality in bleached state than only elevated temperatures (Cróquer and Weil, 2009; Muller *et al.*, 2008). On the positive side, to control the infectious coral diseases phage therapy was found to have potential in which pathogen specific phages not only kills the pathogens but also remain associated with corals and prevent future infections (Efrony *et al.*, 2007). Human inhabitation and fishery/fishing status have direct influence on the microbial community in reef environment (Dinsdale *et al.*, 2008). The corallivorous fishes also act as controlling agent. Predatory fishes were observed feeding upon the infected tissues which resulted into slower progression of the disease (Cole *et al.*, 2009). The human sewage entering into reef environment may trigger disease outbreak in corals. In Caribbean reefs, microbes from human feces were common link between white pox disease, vectors and surrounding environment (Sutherland *et al.*, 2010).

1.5.2 NATIONAL REVIEW:

Indian coral reefs have been studied for extent, management issues and socio-economic aspects (Hoon, 1997; Hoon, 2002; Muley *et al.*, 2002). However, majority of ecological studies on Indian reefs remained limited to the diversity, distribution and assemblage patterns of hard corals and other associated fauna and flora. Early studies by C.G.S Pillai documented scleractinians' diversity from Indian waters with many description of new species and new records (Pillai and Patel, 1988; Pillai *et al.*, 1979;

Pillai, 1969). Recently studies of Gulf of Mannar and Andaman Nicobar reefs have added many new species into account of Indian coral's diversity (Patterson *et al.,* 2007; Venkataraman *et al.,* 2003). The community structures and spatial variations were studied at Gulf of Mannar, Palk Bay and along the Southwest coast of India (Jasmine *et al.,* 2009; Sukumaran *et al.,* 2005; Sukumaran *et al.,* 2008). The associated soft corals from the Indian water are reported from northeast coast of India (George *et al.,* 2007; Thomas *et al.,* 1995; Varghese *et al.,* 2007; Vinod *et al.,* 2007).

Bleaching and tsunami like natural catastrophic events in Indian coral reefs had been given proper attentions (Arthur, 2000; Brown, 1997; Kumaraguru *et al.,* 2003; Kumaraguru *et al.,* 2005; Vivekanandan *et al.,* 2009). South Indian reefs were studied for bio-invasion of macro algae that was reported to gain dominance in the local reef environment and overgrow living colonies (Chandrasekaran *et al.,* 2008; Pereira and Verlecar, 2005).

Indian reefs are very less studied and monitored for disease outbreaks. In 2001, association of fungi was studied with healthy and diseased colonies of *Porites lutea* from Lakshadweep (Ravindran *et al.,* 2001). Subsequent structural and microbial studies revealed the cyanobacterial infection as the cause for the Pink Like Syndrome (PLS) in the *Porites,* however, role of physical environment was also not denied in promoting the PLS in the genus (Ravindran and Raghukumar, 2002; Ravindran and Raghukumar, 2006a; Ravindran and Raghukumar, 2006b). But appearance of pink spots in Porites may be due to trematode larvae infection and not always microbe induced disease (Benzoni *et al.,* 2010). In Gulf of Mannar, total 09 diseases were found common with varied degree of prevalence, with Pink spot dominating the numbers (Thinesh *et al.,* 2009).

1.5.3 Regional review:

Gulf of Kachchh reefs have been studied for diversity, coral cover, bleaching, coral recruits etc. Earlier studies on coral reefs reported coral diversity of this region with difference in total number of species (Chhaya and Patel, 1977; Patel, 1978; Patel, 1985a). Possibilities for coral based industrial development and deleterious effects of

coastal industries were also documented, exploitation of coralline resources from the reef areas by a cement industry had severely affected healthy coral reefs of the nearby area (Patel and Bhaskaran M, 1978; Patel, 1985b). However, the first systematic reporting of 37 species of scleractinians from 15 localities across Gulf of Kachchh was made by Pillai and Patel (1988). Later on there was a huge gap of information on the coral reefs of this region. As adopted to wider range of seasonal temperature fluctuations, the GoK reefs were not found much affected by 1997-98 El-Nino southern oscillation events (Arthur, 2000). Recently new sights of coral formations were reported along the Kachchh district in the northern part of GoK and along the Saurashtra coast also (Deshmukhe *et al.,* 2000; Raghunathan *et al.*, 2004).

1.6 CONSERVATION OF CORALS AND CORAL REEFS:

The coral reefs are of ecological as well as economical values. Economical services of coral reefs are estimated around 30 billion US$ per year (Cesar *et al.*, 2003). The reefs' fish resources cater food requirements of about 500 million people globally, out of them about 30 million of worlds' poorest coastal population are totally dependent on reef resources for their primary means of food production and livelihoods (Gomez *et al.,* 1994; Wilkinson, 2004). Apart from fishery importance, the reefs are "coastguards" protecting the coasts from the cyclones, tsunamis and other nature's furies. They indeed check coastal erosion. But overexploitation of reef resources, coastal development, sedimentation, pollution, global warming, diseases and ocean acidification are amongst the acute threats affecting the integrity of coral reef ecosystems globally (Dixit *et al.*, 2010). The coral reefs are facing degradations worldwide (Souter and Linden, 2005), the Global Coral Reef Monitoring Network (GCRMN) predicted that 20% of global coral reefs have already been degraded beyond recovery, an additional 24% are under imminent threat of collapse, and a further 26% are at long-term risk (Wilkinson, 2004).

All these situations have raised great concern of conservation and sustainable management of reefs and reef resources. Scientific community has taken up extensive reef research to document effects of globally changing environment with help of

thousands of volunteers and non government organizations. To answer the issues of anthropogenic pressures on the fragile coastal/marine ecosystems, a concept of declaring coastal/marine areas reserved to provide legislative cover has become popular for effective protection of vulnerable coastal/marine ecosystems like coral reefs.

1.6.1 Marine Protected Area (MPA):

As per an estimate, 08% of world's population (Wilkinson, 2004) and 26% of Indian population inhabits within 100km of the coast (Anon, 2003). Indiscriminate usage of coastal resources and coastal biodiversity have played major role in altering the habitat and biodiversity adversely, rapid climate change has made the issue more serious. Therefore, a practice became popular to protect coastal or marine resources. As per International Union for Conservation of Nature (IUCN), any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment can be designated as Marine Protected Area (Kelleher, 1999). Thus it is apparent that an MPA always have a part or full of marine environment but in some cases the boundaries may extend over the coast (land areas) also. The effectiveness of Marine Protected Areas' network and their co-operative functioning with other administrations controlling the coastal areas was discussed at length (Keller *et al.*, 2009).

IUCN has defined 6 categories encompassing various objectives and varied priorities for protected areas (Table 1.3).

Table 1.3: IUCN Categories of Protected Areas.

Category	Objectives
I	Protected area managed mainly for science or wilderness protection (Strict Nature Reserve/Wilderness Area)
II	Protected area managed mainly for ecosystem protection and recreation (National Park)
III	Protected area managed mainly for conservation of specific natural features (Natural Monument)
IV	Protected area managed mainly for conservation through management intervention (Habitat/Species Management Area)
V	Protected area managed mainly for landscape/seascape conservation and recreation (Protected Landscape/Seascape)
VI	Protected area managed mainly for the sustainable use of natural ecosystems (Managed Resource Protected Area)

(Kelleher, 1999)

India has vast coastline stretching beyond 7,500km with varied habitats and flourishing diversity (Singh *et al.*, 2004). After the declaration of first MPA of India in GoK, total 38 MPAs have been declared in India so far for conservation and better management of its biological and cultural wealth (Table 1.4).

Table 1.4: List of MPA across India.

No.	Name	State	Legal Status	Year of Est.	Area (km^2)	Biotic Zone
1	Gulf of Mannar (marine)	TN	NP	1986	560.00	8B
2	Sundarbans	WB	NP	1984	1330.10	8B
3	Bhitarkanika	OR	NP	1988	145	8B
4	Marine National Park, Gulf of Kachchh	GU	NP	1982	162.89	8A
5	Rani Jhansi (marine)	AN	NP	1996	256.14	10A
6	Mahatma Gandhi (Wandoor – marine)	AN	NP	1983	281.50	10A
7	North Button	AN	NP	1987	0.44	10A
8	Middle Button	AN	NP	1987	0.64	10A

No.	Name	State	Legal Status	Year of Est.	Area (km^2)	Biotic Zone
9	South Button	AN	NP	1987	0.03	10A
10	Malvan (marine)	MH	WLS	1987	29.12	8A
11	Marine Sanctuary, Gulf of Kachchh	GU	WLS	1980	295.03	8A
12	Khijadiya	GU	WLS	1981	6.05	8A
13	Sajnekhali	WB	WLS	1976	362.04	8B
14	Lothian	WB	WLS	1976	38	8B
15	Haliday	WB	WLS	1976	5.95	8B
16	Bhitarkanika	OR	WLS	1975	672	8B
17	Gahirmatha (marine)	OR	WLS	1997	1435	8B
18	Chilika	OR	WLS	1987	15.53	8B
19	Coringa	AP	WLS	1978	235.70	8B
20	Pulicat	AP	WLS	1976	500.00	8B
21	Krishna	AP	WLS	1999	194.81	8B
22	Point Calimere	TN	WLS	1967	17.26	8B
23	Pulicat	TN	WLS	1980	153.67	8B
24	Lohabarrack	AN	WLS	1987	100	10A
25	North Reef Island	AN	WLS	1987	3.48	10A
26	South Reef Island	AN	WLS	1987	1.17	10A
27	Cuthbert Bay	AN	WLS	1987	5.82	10A
28	Cingue	AN	WLS	1987	9.51	10A
29	Galathea	NI	WLS	1997	11.44	10B
30	Parkinson Island	AN	WLS	1987	0.34	10A
31	Mangroves Island	AN	WLS	1987	0.39	10A
32	Blister Island	AN	WLS	1987	0.26	10A
33	Sandy Island	AN	WLS	1987	0.26	10A
34	Pitti	LK	WLS	2000	0.01	10B
35	Sundarbans	WB	TR	1973	2,585	8B
36	Gulf of Mannar	TN	BR	1989	10,500	8B
37	Sundarbans	WB	BR	1989	9,600	8B
38	Great Nicobar	AN	BR	1989	885	10A

States: TN - Tamil Nadu; AP - Andhra Pradesh; OR - Orissa; WB - West Bengal; GU - Gujarat; MH - Maharashtra, AN - Andaman and Nicobar, NI - Nicobar, LK – Lakshadweep.

Legal status: NP - National Park; WLS - Wildlife Sanctuary; BR - Biosphere Reserve; TR - Tiger Reserve

1.7 Marine National Park and Sanctuary, Gulf of Kachchh:

The Gulf of Kachchh in Gujarat is bestowed varied kind ecosystems and habitat. The lush green mangrove forests fringe the gulf's coasts, where as it harbors dynamic coral reef ecosystems along the southern coast. In the beginning of 20th century, Mr. James

Hornell - a British naturalist was commissioned by the Maharaja Sayajirao Gaikwar of princely Baroda state to study marine life of Okhamandal, he has mentioned occurrence of corals in this region (Hornell, 1909; Hornell, 1916). In the mid of 20th century, Gideon *et al.* (1957) attempted to describe coral diversity of GoK reefs followed by Chhaya and Patel (1977), Patel (1978) and Pillai *et al.* (1979). Detailed account of scleractinian corals was given by (Pillai and Patel, 1988). However, during last few decades of the century the deleterious effects of excess exploitation of reef resources were brought to the society (Patel, 1985b).

The importance of conservation aspects of dynamic yet fragile coral reef ecosystems of GoK accepted and thought of a Marine Protected Area (MPA) was conceptualized. To promote conservation, sustainable development and scientific management of the coral reef ecosystems, Government of Gujarat declared India's first MPA in the Gulf of Kachchh the Marine Sanctuary in August, 1980 initially covering 220.71 km^2 of area which was further expanded in following years to 295.03 km^2. In 1982, 162.89 km^2 of core area of Marine Sanctuary was notified as Marine National Park vide notification No. *AKH-138-(2)-82-WLP-1081-126827-V2* dated 20-7-1982 to enhance the protection level to the coral reef ecosystems (Rajagopalan, 2008; Singh *et al.*, 2004). Thus, the Marine National Park and Sanctuary (MNP & S) covers total of 457.92 km^2 area along the coast of Jamnagar district in the southern Gulf of Kachchh (Fig. 1.5). Of total 42 islands, 37 islands have coral reefs. The immediate effect of declaring the MPA was to cease the sand mining lease given to the industries. The MNP & S falls under protected area **Category II** defined by IUCN.

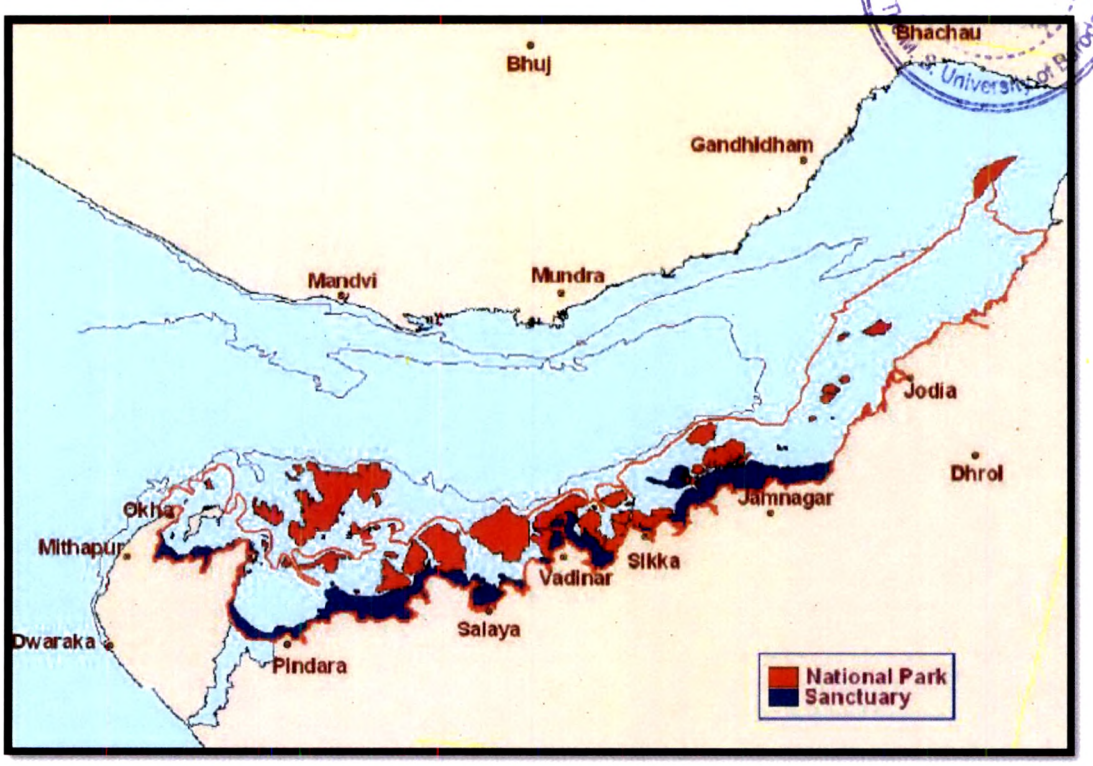


Fig. 1.5: Marine National Park and Sanctuary in Gulf of Kachchh (Source: ICMAM, 2002).

1.8 LACUNA:

The GoK reefs are less studied compared to other Indian reefs in all manner (see 1.5.3). The studies conducted so far were mainly limited to the biodiversity assessment, impact of industries, effect of natural disasters, and a few EIA studies. The studies covering entire MNP & S are seriously lacking vital information; the studies attempted to document distribution of hard corals in various reefs of MNP & S, but failed to provide information on the point level distribution and assemblage. Further, except a few EIA studies carried out by National Institute of Oceanography, no data is available on physico-chemical parameters at important coral areas. Recent study on the economic valuation of GoK reefs has attempted to focus on the revenue generated by eco-tourism and fish resource harvesting from this region. But still no systematic

efforts have been taken up to understand the effects of all such activities on the ecology of the reef area.

In short, there was a need to plan a study selecting a reef area as model to understand the hard corals' distribution, changes in basic physico-chemical environment, associations among the reef fauna and flora etc. in the GoK reefs.

1.9 Aim and Objectives:

With above mentioned lacuna present study was planned mainly with academic interest to understand the basics of a popular reef area of MNP & S - **the Narara reef**. On the basis of observations made and results obtained, recommendations for better conservation practice of this area to be made. To achieve this aim following objectives were set forth:

1. To study the Scleractinian diversity and distribution of the reef area and to assess its status.
2. To study the coral reef associated fauna and flora.
3. To evaluate physico-chemical nature of water of study area.
4. To understand the anthropogenic activities and its impact.

1.10 Flow of the Thesis:

The thesis is written in 07 chapters on scientific discussions. Chapter 1 covers brief introduction to corals, coral reefs and reef ecology supported by relevant literature. Chapter 2 introduces study site, methodology for planned study and describes habitat. Status of scleractinians – diversity, distribution and health are dealt in Chapter 4. The reef is the assemblage of flora and fauna; here in this chapter 5 the associated fauna and flora are discussed. Chapter 6 represents the facts of anthropogenic activities and their potential threats to this reef. Overall observations of this study are reported as discussion followed conclusion and concise summary.